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LIMNOLOGICAL DATA AND PRIMARY PRODUCTION ASSESSMENT IN TASAUL LAKE DURING 2006-2007

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ABSTRACT

The paper presents the most important limnological parameters measured in the water column of Tasaul Lake (a shallow Black Sea coastal lake), during 2006-2007: temperature, dissolved oxygen, pH, total inorganic carbon (TIC), conductibility, photosynthetically active radiation (PAR), chlorophyll *a*, primary production (PP), assimilation number (AN), α and β coefficients involved in P-I (productivity-light intensity) relation.

The mean values of the water column for the mentioned parameters showed that Tasaul Lake is permanently and completely mixed, and an hypereutrophic lake.

Thus, dissolved oxygen (7.43-16.09 mg/l), pH (8.61-9.57), conductibility (1.44-1.85 mS/cm), TIC (61.73-107.38 mg/l), chlorophyll *a* (48-377.40 mg/m^3), PPmax (71-935 766 mgC m^{-3}h^{-1}), AN max (0.48- 5.50 mg C mg^{-1} chl a h^{-1}) indicated the trophic state of the lake.

The annual primary production was 500 to 600 g C /m^3 y.

The aim of these analyses is to assess the algal blooms, to understand aquatic ecosystem processes and to take measures for reducing eutrophication.

KEY-WORDS: limnology, primary production, C-assimilation, ^{14}C-acid bubbling method (ABM), *in situ* incubation, Tasaul Lake, shallow lake

AIMS AND BACKGROUND

The most classical fundamental studies on lake ecology have been done in relative deep lakes, which are in summer subjected to thermal and chemical stratification.

Comprehensive theoretical studies about shallow lake ecosystem started to emerge only in the last two decade (KUFEL *et al*., 1997; MOSS *et al*., 1997; JEPPENSEN *et al*., 1998; SCHEFFER, 2004) and their authors agree that there is still much unknown.

Still there is a long way from a full comprehension of the shallow lakes ecosystem, which includes a full set of physical-chemical (bottom-up) and biological (top-down) interactions (JENSEN *et al.*, 1994; JEPPENSEN *et al*.,1998).

Because of insufficient knowledge about the shallow lake ecosystems it cannot adequately predict their future in the rapidly changing global environment. Also the results of different restoration methods remain incalculable (ZINGEL *et al*., 2006).

Tasaul Lake, situated 20 km north of Constanta on the central Romanian Black Sea coast, is an ecosystem classified as Important Bird Area by Birdlife International. In the 1920s, the former lagoon was altered significantly by hydro-technical constructions and turned into a freshwater system.

The shallow lake (max. depth 4 m) is threatened by various polluters such as industry (hazardous substances, detergents, pesticides), domestic wastewater effluents and solid waste deposits (nutrients, organic carbon), and agriculture (nutrients, fertilizers).

Eutrophication (algal blooms) and over-exploitation have reduced biodiversity and fish populations with economical and ecological value. The serious hypoxia phenomenon is often observed during the summer season.

The collaborative effort between Romanian and Swiss institutions, under the ESTROM Project ”The assessment of anthropogenic impacts on Tasaul Lake, Romania, and ecosystem rehabilitation”, contributed to a better understanding of the problem of eutrophication and has performed a more effective control of nutrients enrichment in Tasaul shallow lake.

The proposed phytoplankton-monitoring between 2005 and 2007 has been designed to detect and monitor changes in plankton production in relation to changing water quality conditions. As dominant producers in Tasaul Lake are the base of food chain for many higher tropic levels. Excessive blooms of plankton species are considered evidence of eutrophication and are known to degrade water quality and block light to submerged aquatic vegetation. Sampling was performed in conjunction with Tasaul Lake phytoplankton, chlorophyll *a* and water quality monitoring program: on surface network collecting between 2005 and 2006 on water column, between 2006-2007.

The ^{14}C acidification and bubbling method (ABM, STEEMAN NIELSEN, 1952, modified by GACHTER & MARES, 1979) has been introduced as a new methodology in Romania, for the assessment of the primary production in phytoplankton of Tasaul Lake during 2006 and 2007 under Swiss Water Institute EAWAG assistance. It is important to understand Tasaul Lake’s functioning and eutrophication, in the aim of ecological rehabilitation and according with EU Directives.

This method is considered more sensitive and precise, offering several advantages than other known techniques (oxygen method, filtration method) which are used for the determination of the photosynthetic activity of phytoplankton.

MATERIALS AND METHODS

Vertical profiles of limnological key parameters, such as temperature, pH, conductivity, alkalinity, TIC (total inorganic carbon), dissolved oxygen, underwater light regime, surface radiation (PAR), chlorophyll *a* and ^{14}C- assimilation (C-Ass) were assessed in the water column (0-3.5 m) of Tasaul Lake, monthly, between 2006 and 2007.

PHYSICAL FACTORS

In situ photosynthetically active radiation [PAR, denoted as ($\mu E\ m^{-2}\ s^{-1}$)] was measured with a scalar quantum sensor (LI 190 SB) connected to an integrating quantum meter (LI 188) made by LI-COR Inc, USA. Simultaneously a cosine corrected PAR sensor (LI 190) served as a reference, measuring PAR above the water surface.

Surface radiation: PAR was continuously monitored over intervals of 15 min. on the roof of the National Institute for Marine Research and Development “Grigore Antipa”, Constanta (NIMRD), using the same types of sensors like in underwater regime.

Ultraviolet radiation (UV-A), was assessed in $\mu W\ m^{-2}$ with a flat sensor (Maccam-SD 104A-COS). A second spherical sensor served as a reference, measuring UV-A simultaneously above the water surface. The inherent difference between the two sensor types, the PAR sensor measuring photons while the UV sensors energy, impedes a precise direct comparison of the two types of measurements.

The measurements were made at each 10 cm in depth from the water surface in the euphotic zone of lake.

TEMPERATURE, CONDUCTIVITY AND OXYGEN

Temperature (^oC), conductivity (mS/cm) and dissolved oxygen (mg/l) were measured *in situ* with an YSI (Yellow Spring Instrument) 556 MPS (Multi-Probe-System) made by YSI Inc., USA. The measurements were undertaken on profiles in water body at 0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5 meters.

CHEMICAL PARAMETERS

Alkalinity (mg $CaCO_3$/l) *was titrated according to Standard Method SR ISO 9963, SR ISO 9963-2.*

Total inorganic carbon (TIC-mg/l) was determined from alkalinity and pH according to RHODE (1958,1994) and GOLTERMANN *et al.* (1978). The measurements were carried out on the same water profiles like those for temperature, conductivity and dissolved oxygen.

BIOLOGICAL PARAMETERS

Chlorophyll a (µg/l, mg/m^3):

Chlorophyll *a* was measured at depths of 0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5 m (in µg/l).

Sample preparation and chlorophyll *a* extraction were performed according to International Standard ISO 10260 (SCOR-UNESCO, DEV 1972-1989, as described in FINGER *et al*. 2007)**.**

Samples were filtered through Millipore 0.45 µm GF/F fiberglass filters. The filters were put in Sovirel tubes filled with 8 ml of 90 % ethanol. Chlorophyll *a* was extracted by heating the samples (for 10 min) in a water bath at 75^{o}C. Before spectrophotometric analysis (UV-VIS SPECORD 205, at 665 nm and 750 nm), the chlorophyll *a* extracts were filtered through Millipore Millex FG 0.2 µm membrane filters.

Primary Production (PP; ^{14}C - Assimilation, in mg C m^{-3}h^{-1})

Water samples were taken in general at 0, 0.12, 0.25, 0.37, 0.5, 0.75, 1.0, 1.5, 2.0, 2.5, 3.0 meters depth, and *in situ* measurements were performed in 100 ml Duran bottles at each specific depth (BOSSARD *et al.,* 2001). The profiles were chosen and adapted to Secchi disk measurements. The incubation took place for three hours, generally in the morning in interval 10.00 to14.00 local time, after addition of 5 µCi $NaH^{14}CO_3$ per bottle. From each of the sample taken in the lake between 0 and 1 meters, sub-subsamples were incubated *in situ* in Duran bottles covered with a UV-screen (transparent hard PVC tube according to BUHLMANN *et.al*.,1987) to measure the difference in ^{14}C - assimilation, when UV radiation is removed. After incubation, the samples were immediately transported in the radioactivity laboratory of NIMRD, processed by the acidic bubbling method. Radioactivity was determined by liquid scintillation counting (Tri-Carb 1000, Hewlett Packard, USA), after addition of 10 ml Instagel (Packard, USA) to 7 ml water sample in glass vials of 20 ml volume.

The Assimilation Number (AN) was calculated as C- assimilation per chlorophyll *a* [mg C (mg chl *a*)$^{-1}$h^{-1}].

RESULTS AND DISCUSSIONS

Temperature, dissolved oxygen, pH, conductivity, TIC

Temperature has a significant influence on the chemical and biological processes, diminishing or accelerating the metabolic processes. The temperature and oxygen are well correlated in Tasaul Lake water.

The temperature values were normal for these periods. The smallest values were generally measured in the lower part of the water column, and the highest, in the upper part.

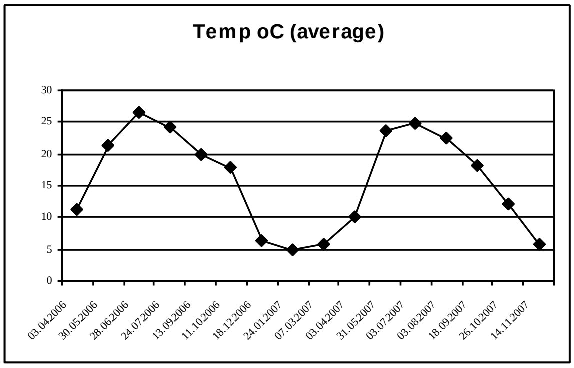
Vertical profiles in 2006-2007 showed that Tasaul Lake seemed not to be stratified at all, except in winter when the lake was frozen (inverse stratification). The stratification behavior is governed by the variable weather and wind conditions, large wind fetch and shallow depth (maximum 4 m).

The maximum mean values were achieved in June 2006 and July 2007 (summer) and minimum, during winter period (Fig. 1).

Dissolved oxygen is essential to the respiratory metabolism of most aquatic organisms. The dynamics of oxygen distribution in inland waters are governed by a balance between inputs from the atmosphere and photosynthesis and losses from chemical and biotic oxidations.

Oxygen distribution is important for the direct needs of many organisms and affects the solubility and availability of many nutrients and therefore the productivity of aquatic ecosystems (WETZEL, 2001; DODDS, 2002).

The smallest values for oxygen were registered in June 2006 (0.33-11.94 mg/l) and August 2007 (5.40-10.15 mg/l), when also the water temperatures in depth profiles were very high, during the whole period of observation. Even under these conditions, the lake water contains a high quantity of oxygen in the euphotic zone, which permits a good progress of biochemical metabolism in aquatic life ecosystem per whole. In July 2006 (8.71-17.11 mg/l), December 2006 (13.43-14.46 mg/l) and January 2007 (15.78-10.60 mg/l), April 2007 (15.47-16.22 mg/l), November 2007 (12.5-13.82 mg/l) the oxygen content was very high in the whole water column (Fig.1).



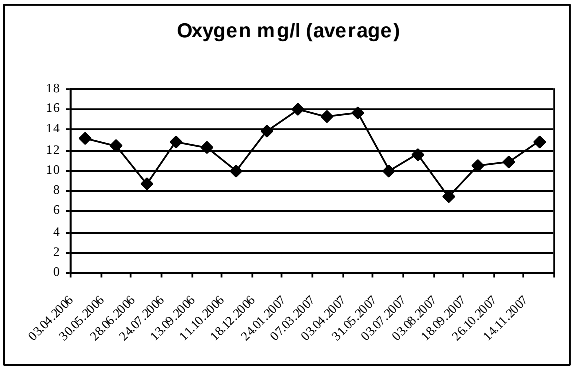


Fig. 1 Monthly mean values of temperature and dissolved oxygen in the water column

The high pH values (8.61 - 9.57) indicate a high alkaline water, and high values in TIC, especially in December 2006 (74.7-76.6 mg/l) and July 2007 (102.5-110.2 mg/l) were associated (Fig. 2). The last parameter indicates a high quantity of inorganic carbon in lake water, which is necessary for photosynthesis and generation of organic substance. The smallest values for TIC were measured in May 2006 (66.6-62.4 mg/l) and January 2007 (69.1-72.6 mg/l).

TIC in Tasaul Lake is 2-3 fold higher than in oligotrophic Lucerne Lake (cca. 25 mg/l) and Brienz (cca. 18-19 mg/l), Switzerland (BOSSARD *et al.*, 2001; FINGER *et al.*, 2007).

The pH of natural waters is governed to a large extend by interaction of H^+ ions arising from the dissociation of H_2CO_3 and from OH^- ions produced during the hydrolysis of bicarbonate.

The range of pH of most open lakes is between 6 and 9. Most of these lakes are the “bicarbonate type”. Calcareous hardwater lakes are commonly buffered strongly at pH values > 8.

pH in surface waters varies seasonally and vertically in lakes in relation to loading from allochthonous sources, physical conditions, and biotic inputs and consumption.

The higher pH values indicates intense photosynthetic processes, proved by high chlorophyll *a* values. The photosynthesis uses up hydrogen molecules, which causes the concentration of hydrogen ions to decrease, therefore the pH values increase. Besides seasonal changes, daily variation can affect pH values. The biological activity of aquatic plants affects pH values, especially at the top of the lake. The plants uses CO_2, pH value increases, but the photosynthesis decreases and respiration increases, decomposition processes lower pH values (WETZEL, 2001; DODDS, 2002).

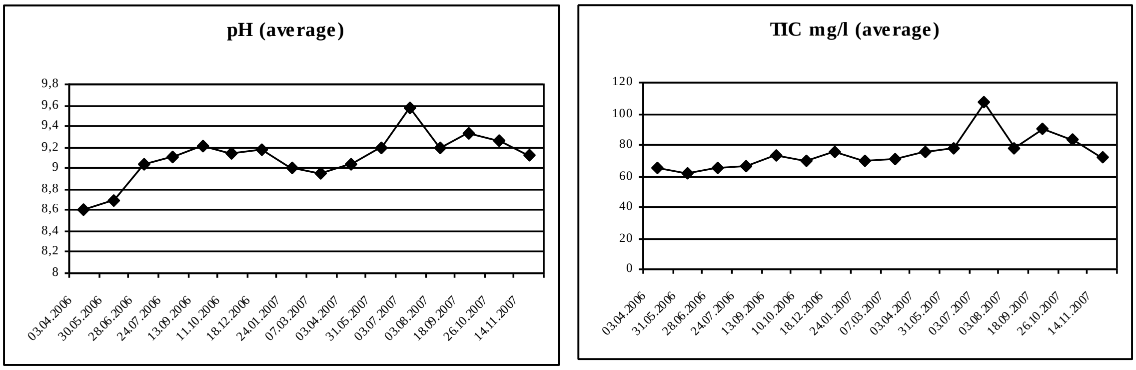


Fig. 2. Monthly mean values of pH and TIC in the water column

Inorganic carbon, largely as dissolved carbon dioxide and bicarbonate, is the primary source of carbon for photosynthesis and generation of organic substance. These organic compounds are generated by cyanobacteria, algae, and higher plants both within the lakes or rivers and externally within drainage basins and variously imported to the water bodies. These organic carbon-based compounds provide the materials and energy for subsequent metabolism within the ecosystem. Inorganic carbon utilization is balanced by respiration production of CO_2 and HCO_3^- from incoming water and from the atmosphere.

The total inorganic carbon concentration in fresh water depends on the pH, which is governed largely by buffering reactions of carbonic acid and the amount of bicarbonate and carbonate derived from the weathering of rocks. The most important carbonate of aquatic systems is $CaCO_3$. The solubility of CO_2 increases markedly in water that contains carbonate (WETZEL, 2001; DODDS, 2002).

The conductivity indicated the smallest values in June 2006 (1.437-1.459 mS/cm), May 2007 (1.66-1.662 mS/cm) and the highest in December 2006 (1.791-1.794 mS/cm), January 2007 (1.849-1.852 mS/cm), Fig.3. The conductivity is first correlated with nutrient concentrations, being a sum of ionic compounds.

Conductivity can be correlated approximately to system productivity because high nutrient waters have high conductivity, but other factors including concentration of non-nutrient salts also influence conductivity. The value for total dissolved solids does not always exactly correlate to that of conductivity. Only ionic compounds are included in conductivity, whereas unchanged molecules (such as many dissolved organic compounds) also contribute to total dissolved solids (WETZEL, 2001; DODDS, 2002).

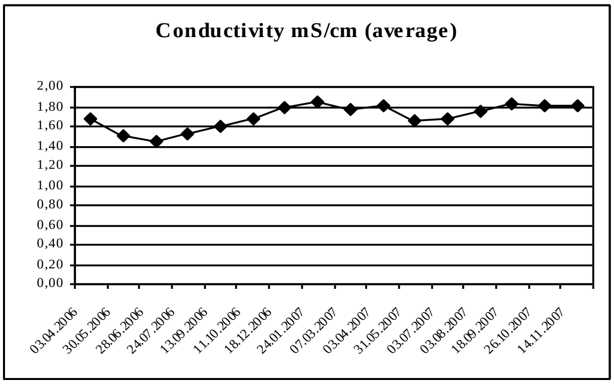


Fig. 3. Monthly mean values of conductivity in the water column

Chlorophyll a

The chlorophyll *a* content and areal registered the smallest values in December 2006 (46.22-49.83 µg/l), April 2007 (13.68-74.9 µg/l) and the highest values in May 2006 (202.32-258.14 µg/l), August 2007(351.17-417 µg/l) in whole depth profiles of Tasaul water (Fig. 4).

The areal of chl *a* follows the same shape as Chl *a* concentration and in both cases the biggest values were registered in 2007 (>1000 Chl *a*/m^2) starting with July till the end of year, (Fig. 4). Chlorophyll *a* concentration varied between 134 and 1025 mg chl *a* m^{-2}.

Comparatively in Harku Lake (Estonia), which is an eutrophic shallow lake, the average anuual value for chlorophyll *a* was 230.4 chl *a* m^{-3} (ZINGEL *et al*., 2006).

The very high content of chlorophyll *a* is correlated with a high density of phytoplankton and high concentration of nutrients which are responsible of algae development. Chlorophyll *a* is considered the principal variable to be used as a trophic state indicator. There is generally a good agreement between planktonic primary production and algal biomass, and algal biomass is an excellent trophic state indicator.

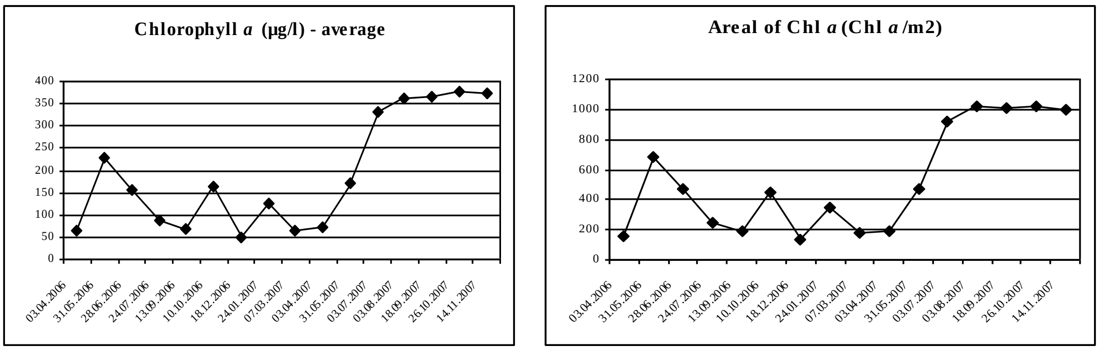


Fig. 4. Mean values of chlorophyll *a* and areal in the water column

Photosynthetically Available (Radiation PAR)

Solar radiation is the major energy for aquatic ecosystems. The productivity and internal metabolism are driven and controlled by energy derived directly from solar energy utilized in photosynthesis. In addition, absorption of solar energy and its dissipation as heat affects the thermal structure, water mass stratification, and hydrodynamics of lakes and reservoirs. These characteristics have marked attendant effects on all chemical cycles, metabolic rates, and population dynamics (WETZEL, 2001; DODDS, 2002).

PAR was expressed in % of subsurface value Io and indicated a high light penetration in water column in April 2006 and January, March, April 2007 (2.5 m) and for the rest of the year till 1 m depth due to high turbidity. This parameter is correlated with water transparency and algal bloom and is an important factor which influences primary production. Actually, PAR indicates the region in lake water, in which primary production is developed. The PAR values are the highest during the summer period (1375-1509 µE/m^{2}s), (Fig. 5).

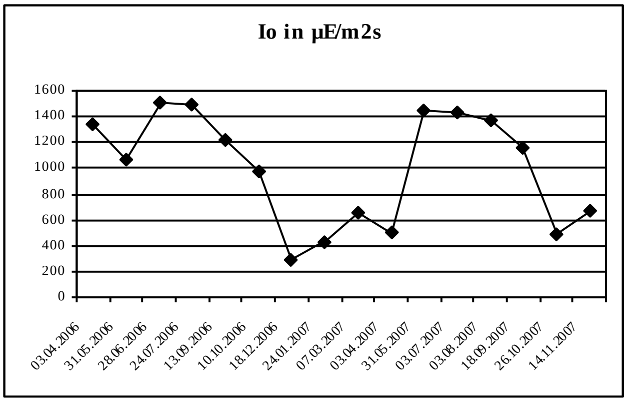


Fig. 5. The values of PAR at Tasaul Lake surface

The euphotic zone is defined as the depth at which the light intensity of the photosynthetically active spectrum (400-700 nm) equals 1% of the subsurface light intensity (from photometric measurements with a Spherical Quantum Sensor and a DataLogger) (WETZEL, 2001; DODDS, 2002).

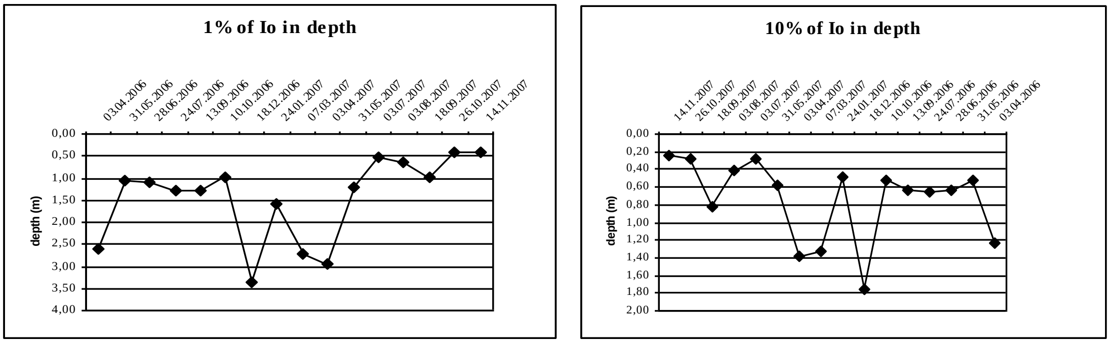


Fig. 6. The euphotic zone of Tasaul Lake

Excepting April, December 2006 and March, April 2007, when the layer of primary production was large up to 2.6-3.35 m, in the rest of studied period the layer was maximum up to 1m (Fig. 6).

Primary production (C-assimilation)

The primary production of phytoplankton is often used as a major criterion for determining the state of a lake or reservoir. The validity of this criterion depends upon the assumption that the dissolved and the particulate organic matter inputs from littoral and allochthonous sources are minor relative to those of the phytoplankton. In many cases on a global basis, littoral productivity and allochtonous organic inputs are much larger than inputs produced by phytoplankton productivity; in such cases, phytoplankton productivity alone is a poor estimation of the trophic state of the lake or reservoir. Such analyses do not decrease the importance of phytoplankton to the metabolism and food-web structure of lakes and reservoirs.

Rather, the primary productivity of phytoplankton must be viewed as a variably important contributor to overall aquatic metabolism (WETZEL, 2001; DODDS, 2002). Primary production was assessed in two variants, with and without UV light to see in which way the UV light influences C-assimilation.

The maximum values in both cases were achieved in June 2006 (758.766 mgC $m^{-3}h^{-1}$with UV light and 816.651 mgC $m^{-3}h^{-1}$ without UV light) and in generally C-ass without UV light was higher than C-ass with UV light, except April and October.

In 2007 the highest values for C-ass were achieved in October (935.42 mgC $m^{-3}h^{-1}$with UV light) and August (1129.155 mgC $m^{-3}h^{-1}$without UV light) (Fig. 7). So, in Kaiavere Lake (Estonia), which is an eutrophic shallow lake, C-ass max ranged between 45-180 mgC $m^{-3}h^{-1}$(ZINGEL *et al.*, 2006). Daily production ranged between 273 and 3798 mg C m^{-2} d^{-1} with an efficiency (assimilation number) of 0.03-0.71 mg C (mg chl *a*)$^{-1}$$h^{-1}$.

PP must be evaluated over an annual period to have an entire view regarding lake productivity. Preliminary estimates yield an annual production of 500 to 600 g C m^{-2} y^{-1}, which correspond to a highly eutrophic status of the lake.

E.g. in Brienz Lake which is an ultra-oligotrophic lake, annual gross primary production was 70 g C m^{-2} y^{-1}, and in Lucerne Lake, which is a peri-alpine lake, 160 gC$m^{-2}y^{-1}$(GAMMETER *et al.*, 1996; FINGER *et al.*, 2007).

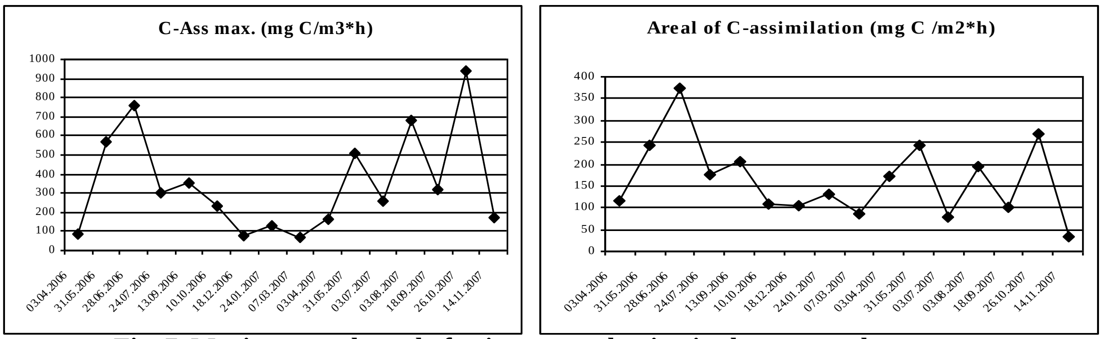


Fig. 7. Maximum and areal of primary production in the water column

Assimilation number (AN)

The Assimilation Number (AN) was calculated as C- assimilation per chlorophyll *a* [mg C (mg chl *a*)$^{-1}$h^{-1}].

The most important value is AN max, which indicates maximum of productivity and ranged between 0.48-5.50 mg C mg^{-1} chl *a* h^{-1} in water column (Fig. 8).

AN showed the max value in September 2006, (5.50 mg C mg^{-1} chl *a* h^{-1}) and in 2007, AN was maxim in April (2.86 mg C mg^{-1} chl *a* h^{-1}).

The areal of AN ranged between 0.03-0.97 mg C (mg chl *a*)$^{-1}$h^{-1}, during of all period of observation (Fig. 8).

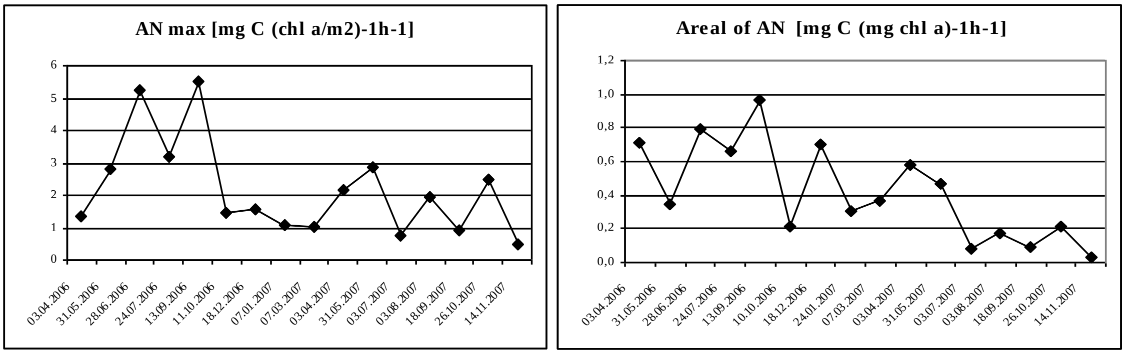


Fig. 8. Maximum and areal of assimilation number in the water column

The measured ANmax is rising from spring towards summer and falling from summer to winter. This means that the specific efficiency of C-assimilation per chlorophyll *a* is higher in summer than in winter. This is probably because of higher algal densities in summer which result in a stronger competition between algae for the scarce light below the water surface.

- *P-I (productivity-light intensity)*

The P-I curves show the correlation between primary production and light intensity (PAR).

Curve fitting with the equation:

y=a*(1-e^(n*x/a))*(e^(m*x/a))

(a = ANmax, n = α, m = ß, x = PAR, and y = AN), BOSSARD *et al*., 2001.

can be done quite well at lower PAR intensities, where the curve is rising, but meets some difficulties at inhibitory (higher) PAR intensities.

This may be caused partly by the very high light gradients within a short distance of the vertical profile (in summer light intensity drops from 100% to 5% within one meter), which made it difficult to collect enough assimilation data that was evenly distributed on the light axis.

The P-I curve fitting (in the simultaneous mode) yields sometimes unrealistically high coefficients of ANmax which need to be compensated with high coefficients of ß (or vice versa).

For the sampling dates of 30 May and 13 September 2006 it is not possible to fit the curve well. If curve fitting was not satisfactory for the whole light range of the curve, we have selected from a variety of alternate curve fittings the one that fit the data best at lower light intensities, e.g. in such cases we preferred to have more realistic α and ANmax at the cost of good fitting results in the inhibitory range (less realistic ß) (Table 1).

Table 1. Monthly values of AN max, α, ß involved in P-I curve fitting

Date	AN max	alpha α	beta ß
	a	n	m
03.04.2006	5.31	-0.0099	-0.0106
30.05.2006	5.00	-0.0080	-0.0008
28.06.2006	6.93	-0.0971	-0.0111
24.07.2006	10.00	-0.0139	-0.0150
13.09.2006	10.00	-0.0250	-0.0100
10.10.2006	7.00	-0.0109	-0.0150
18.12.2006	8.00	-0.0300	-0.0500
24.01.2007	1.25	-0.0650	-0.0015
07.03.2007	4.00	-0.0110	-0.0120
03.04.2007	5.50	-0.0130	-0.0100
31.05.2007	8.00	-0.0090	-0.0080
03.07.2007	0.80	-0.00300	0.00000
03.08.2007	no curve fits possible		
18.09.2007			
26.10.2007	9.00	-0.01500	-0.0150
14.11.2007	19.01	-0.00020	0.0355

We justify this, because inhibition of C-assimilation can be less easily assessed *in situ* than C-assimilation in the light limiting (lower) part of the curve. The observed very low C-assimilation near the surface may have been enhanced by a bottle effect and thus be an experimental bias. Light inhibition is mainly caused by UV and to a lesser extent by high PAR intensities. Inhibition is the result of the light dose (light intensity x incubation time of the bottle).

The light dose of a freely floating alga may be different from the light dose of an alga enclosed in a bottle, because it cannot move up and down during incubation. Therefore algae enclosed in a bottle near the surface cannot regenerate in a water layer of low light intensity in between two expositions to high light intensities. With the help of UV-filters applied to one of two bottles at each depth near the surface, we get some information about the inhibitory effect and the absence of it (upper and lower range of inhibition).

CONCLUSIONS

1.Tasaul Lake is permanently and completely mixed, from top to bottom and is a holomictic lake,

2. Chlorophyll *a* concentration and primary production values correspond to a highly eutrophic status of the lake,

3. The measured limnological parameters registered high values and support the conclusion that Tasaul Lake is an hypereutrophic lake.

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